Comparison of Data Used to Establish Intra-plant Distance Tables to Predictive Models

By

Lon D. Santis[1],
John W. Tatom[2], and
Michael M. Swisdak[3]

Nearly 100 explosives events that occurred at the turn of the 20th century have been compared to the predictions of explosion consequence models. Events and data used for the establishment of the original Institute of Makers of Explosives' Intra-plant Distance Tables were simulated in the computer models IMESAFR, and DIRE. Scenarios with over 500 individuals exposed inside K40 in were replicated in the models. The data were separated into open, not open, barricaded, and unbarricaded scenarios. Comparisons of the models' predictions to the results of the actual events indicate that the models are typically conservative, but more or less within an order of magnitude depending on the scenario. Relevance of the nearly 100 year-old data and potential improvements for the models are discussed.

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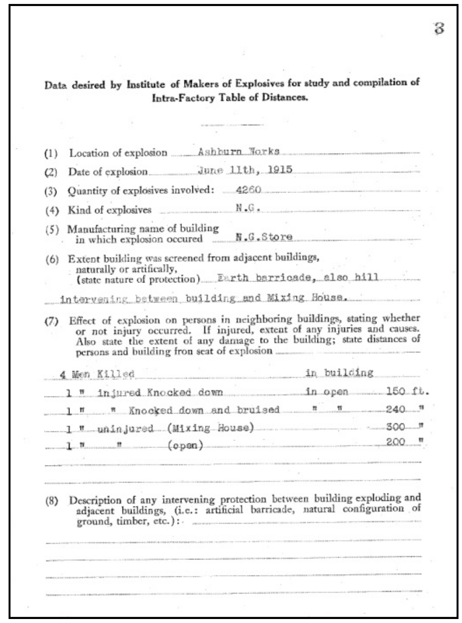
Introduction

In early 2009, representatives of the US Army Engineering and Support Center in Huntsville, AL, visited the IME to research the origins of the DoD intra-plant distance tables. This visit was essential to their research since the DoD intra-plant table was initially copied from the IME intra-plant table. To understand the origins of the DoD tables it was necessary to understand the origins of the IME tables. Within the IME files was a report titled <u>Data in Regard to Explosions - Intra-Plant Table of Distances,</u> compiled by Ralph Assheton and dated April 23, 1923. The report chronicled 111 accidental explosion events in explosives manufacturing plants from 1880 to 1916. Each event was described on a form shown in Figure 1.

The report recorded the type and amount of explosive involved in the incident and the effects and distances to nearby buildings and workers. Symbols for the type of injury in about 80 of the incidents were plotted on an oversized chart with a Y-axis of pounds of explosive and an X-axis of distance from explosion. A curve labeled "intra-plant distances (barricaded)" cut through the symbols such that all of the fatalities and most of the serious injuries were to the left of the line.



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Data desired by Institute of Makers of Explosives for study and compilation of Intra-Factory Table of Distances.

(1) Location of explosion Ashburn Works

(2) Date of explosion June 11th, 1915

(3) Quantity of explosives involved: 4260

(4) Kind of explosives N.G.

(5) Manufacturing name of building in which explosion occured N.G.Store

(6) Extent building was screened from adjacent buildings, naturally or artifically, (state nature of protection) Earth barricade, also hill intervening between building and Mixing House.

(7) Effect of explosion on persons in neighboring buildings, stating whether or not injury occurred. If injured, extent of any injuries and causes. Also state the extent of any damage to the building; state distances of persons and building fron seat of explosion

4 Men Killed in building
1 " injured Knocked down in open 150 ft.
1 " " Knocked down and bruised " " 240 "
1 " uninjured (Mixing House) 300 "
1 " " (open) 200 "

(8) Description of any intervening protection between building exploding and adjacent buildings, (i.e.: artificial barricade, natural configuration of ground, timber, etc.):

Figure 1. Sample Report on Event

The curve followed the traditional K-factor function:

$$D = 9 \times NEW^{1/3}$$

where:
D = distance from event, and
NEW = net explosive weight involved in event (pounds).

Practically no text besides the individual event records as shown in Figure 1 was found. A note on the cover sheet indicated that the symbols "verify [the] distance curve" and that the other 30 incidents in the report were chronicled "for information." Apparently, this work was never published but served as the origin of the IME's first intra-plant distance table published in 1926.[4]

The intra-plant distance table originally applied to unbarricaded distances and roughly followed a K-factor of 18 (K18). Barricading allowed reduction in the distance by one-half or K9. Today's intra-plant distance table follows K9 and the distances are doubled (K18) if there are no barricades.

It is a common belief that the sole purpose of the intra-plant distance table was to prevent propagation of events from one manufacturing operation to another. This apparently is not the case since the table was originally created to protect workers from "serious injuries" and propagation of

[4] Amended Pamphlet No. 3, Suggested State Law, IME, New York, NY, 1926.

events.[5] The latter was probably based on the IME members' experience with propagation events, of which they had plenty at the time. Since no data in support of using the table to prevent propagation has been found, the creators probably had the opinion that propagation was very unlikely at the distances needed to protect workers from the primary event. Rather than the sole reason, preventing propagation was an outcome of trying to prevent serious injury to workers from an event with the intra-plant distance table.

Preparation of the Data for Fresh Treatment

Each incident report gathered by Assheton was reviewed and the relative data from each event tabulated. Of the 111 events chronicled in his report, 92 involved at least one person exposed with reasonably discernable data. Some incident reports contained data that was ambiguous or incomplete, in which case the data were not included. For example, one unused report simply said "Employees – slight or no injury 180 to 900 ft." For useable event reports, the location of the incident, date, NEW, type of explosive involved, PES type, presence of barricades, injury type, number of injuries of that type, ES type, distance from PES, and percent building damage were tabulated for each PES-ES pair. In the end, 220 distinct PES-ES pairs were gleaned from the intra-plant report for analysis.

In over 85 percent of the PES-ES pairs, the actual number of people in the ES at the time of the event was reported. Sometimes however, less precise information on the number of individuals exposed was reported, in which case the number was estimated. Table 1 shows the estimated number of individuals used for each of the subjective descriptors used in the intra-plant report.

Table 1. Subjective Exposure Equivalencies

Subjective Descriptor	Estimated Number of Individuals
families in dwellings	15
persons in dwellings	10
many employees	10
many persons in dwelling	6
several	5
family	4
man and children	4
crew	3
persons in dwelling	3
nobody	2
men	2
girls	2
employees	2
no-one	1
no injury	1

Most distances between the PES and ES were reported to the "tens" of feet. Rarely, instead of a precise distance, a range and number of ES within that range were given. For example, one report said "many employees in buildings with 200-500 feet [from event] escaped injury." This was entered as 3 separate exposures without injury; an ES with 3 people at 200 feet, an ES with 3 people at 350 feet, and an ES with 4 people at 500 feet.

The consequences of the various individual exposures were categorized as fatalities, major injuries, minor injuries, and no injury. Major injuries were those that required hospitalization or involved lost work time. Minor injuries

[5] Minutes of Jan. 26, 1917 meeting of the IME, New York, NY.

were those that could be treated with first aid on the scene. Occasionally, injuries were reported using these exact terms, but most of the time, other words were used to describe the extent of injury. Table 2 shows the category used for each injury description as listed in the event reports.

In cases where the description of injury was hard to categorize, supplemental information about the event or injury was used. This information is shown in parentheses in Table 2. Supplemental information from the History of Explosions[6] is shown in italics. Otherwise, the information came from another part of the event report.

Table 2. Categorization of Nonfatal Injuries as Listed in the Intra-plant Report.

Major Injuries	Minor Injuries	No injury
Collar bone broken or fractured	Injured, knocked down	Uninjured
Severe injury on leg	Injured, knocked down and bruised	Unhurt
leg broken	Slight injuries	Not hurt
Seriously injured	Cuts	Not injured
Badly injured	Slight cuts	Not effected [sic]
ribs fractured	Stunned	Escaped injury
struck by missile *(lost an eye)*	nervous shock	
Off work for 5 weeks	Bruises and cuts	
dislocated shoulder	"blown" through window	
Leg injured by collapse of roof	Sprained shoulder	
Somewhat injured (PES collapsed)	Slightly hurt	
Severely injured, shocked, bruised, etc.	Contusions of back	
Badly shocked, broken arm, body contusions	Bruised, shocked, and slight internal injuries *(slightly injured)*	
Eardrum punctured, deep cuts on head, severely shocked		
Injured (another person killed in the same ES or at same distance from event)		
Bruised in body and legs, cuts, visited hospital		
One eardrum punctured, bruised and shocked *(eyes affected)*		

The Data in Relation to Current Standards

Modern explosives risk management focuses on the K-factor of the exposure in an attempt to relate the probability of fatality or injury to the NEW, distance, and other factors. By calculating the K-factor

[6] History of Explosions on which the American Table of Distances was Based, Including Other Explosions of Large Quantities of Explosives, compiled by Ralph Assheton, IME, Press of Charles L. Story, Wilmington, DE, 1930.

for each individual exposure and correlating it to injury type, Assheton's data can be used to better understand these relationships.

There were an estimated 584 individuals exposed to an event with 23 fatalities, 30 major injuries, 149 minor injuries, and 382 individuals uninjured. For each type of injury, the individual exposures were grouped within K factor bins and are shown in Table 3.

Table 3. Number and Type of Injury for K-factor bins. [1]

K-factor Bin	Fatalities		Major Injuries		Minor Injuries		No Injury		Total
1-5	17	33%	9	17%	7	13%	19	37%	52
6-10	3	4%	11	15%	15	20%	46	61%	75
11-15	2	2%	4	3%	52	43%	62	52%	120
16-20	1	1%	2	2%	19	20%	73	77%	95
21-25	0		1	1%	14	20%	55	79%	70
26-35	0		2	3%	19	25%	55	72%	76
36-45	0		1	1%	3	7%	42	91%	46
46+	0		0		20	40%	30	60%	50
Total	23		30		149		382		584

The probability for each bin is also shown in Table 3. Because of the significant increase in the probability of minor injury at K factors above 46, this bin was not included in further analyses. As to be expected with a compilation of close-in exposures, the number of individuals reported as uninjured was significantly underreported at high K factors. This probably also results in a slight overestimation of injury probabilities in the K36-45 and perhaps even the K26-35 bins.

The influence of black powder, exposures in the open, and barricades were previously reported.[7] No differences in injury probability could be found between the black powder data set and the rest of the data. Therefore, black powder events were included in subsequent analyses. Differences were observed in the data subsets of exposures in the open and those screened by barricades. Despite 32 individual exposures in the open from K20 to K40, no-one was injured. Barricades appeared to have had a significant effect on protecting people close the event, but as expected, did little for people farther away.

Comparison of the Data to Risk Modeling Programs

The probability of fatality [P(f)] in the Assheton data was compared to the expected case consequence predictions of two explosives risk modeling programs, DIRE 1.2[8] and IMESAFR 1.1[9]. Each scenario from the Assheton data was recreated in the models and the resultant risks arithmetically averaged within each bin. The P(f) for all exposures; and the data subsets of exposures in the open, exposure not in the

[7] Santis, L.D., A Modern Look at the Origins of Intra-plant Distance Tables, Proceedings of the ISEE 36th Annual Conference, Feb. 7- 10, 2010, Orlando, Florida USA.

[8] Justice, D. Bart and Tatom, Frank B., "Comparison of Real World Data to DIRE Model Predictions," Minutes of 31st DDESB Seminar, 24-26 August 2004.

[9] Tatom, John W., Santis, Lon D., and Leidel, David J., "The Status of Risk Assessment in the Commercial Explosives Community," Minutes of 33rd DDESB Seminar, 12-14 August 2008.

open, exposures with barricades and exposures without barricades were compared. The results are shown in Table 4.

Table 4. Comparison of P(f) for Assheton Data and Models at Various Exposures.

K-factor Bin	All Exposures			Not Open			Open			No Barricade			Barricade		
	Data	IMESAFR[10]	DIRE	Data	IMESAFR	DIRE	Data	IMESAFR	DIRE	Data	IMESAFR	DIRE	Data	IMESAFR	DIRE
1-5	0.33	1	0.91	0.26	1	0.86	0.60	1	1.0	0.35	1	0.90	0/4	1	0.67
6-10	0.040	1	0.32	0.033	1.0	0.33	0.071	0.92	0.21	0.045	1.0	0.29	0/9	1	0.41
11-15	0.017	0.50	0.14	0.017	0.43	0.13	0/5	0.30	0.11	0.019	0.50	0.13	0/17	0.23	0.14
16-20	0.011	0.23	0.061	0.011	0.17	0.062	0/8	0.10	0.028	0.012	0.21	0.061	0/11	0.065	0.073
21-25	0/70	0.033	0.057	0/52	0.10	0.047	0/18	0.094	0.012	0/63	0.10	0.061	0/7	0.083	0.0088
26-35	0/76	0.023	0.0089	0/67	0.012	0.0081	0/9	0.0031	0.0075	0/57	0.017	0.0092	0/19	0.0045	0.0046
36-45	0/46	0.0077	0.0029	0/41	0.0094	0.0015	0/5	0.0026	0.010	0/39	0.013	0.0029	0/7	0.0015	0.00034

In cases where there were no fatalities within a particular K-factor bin, the number of exposures without a fatality is shown as a ratio under zero. For example, within the K21-25 bin there were 70 total individuals exposed without any fatalities occurring. DIRE cannot model barricades, so DIRE's P(f) for barricaded scenarios would be expected to be conservative. The P(f) for "All Exposures" was previously reported and shows worst case risk. All other modeled P(f) are expected case. Figure 2 shows the P(f) for the "Not Open" cases.

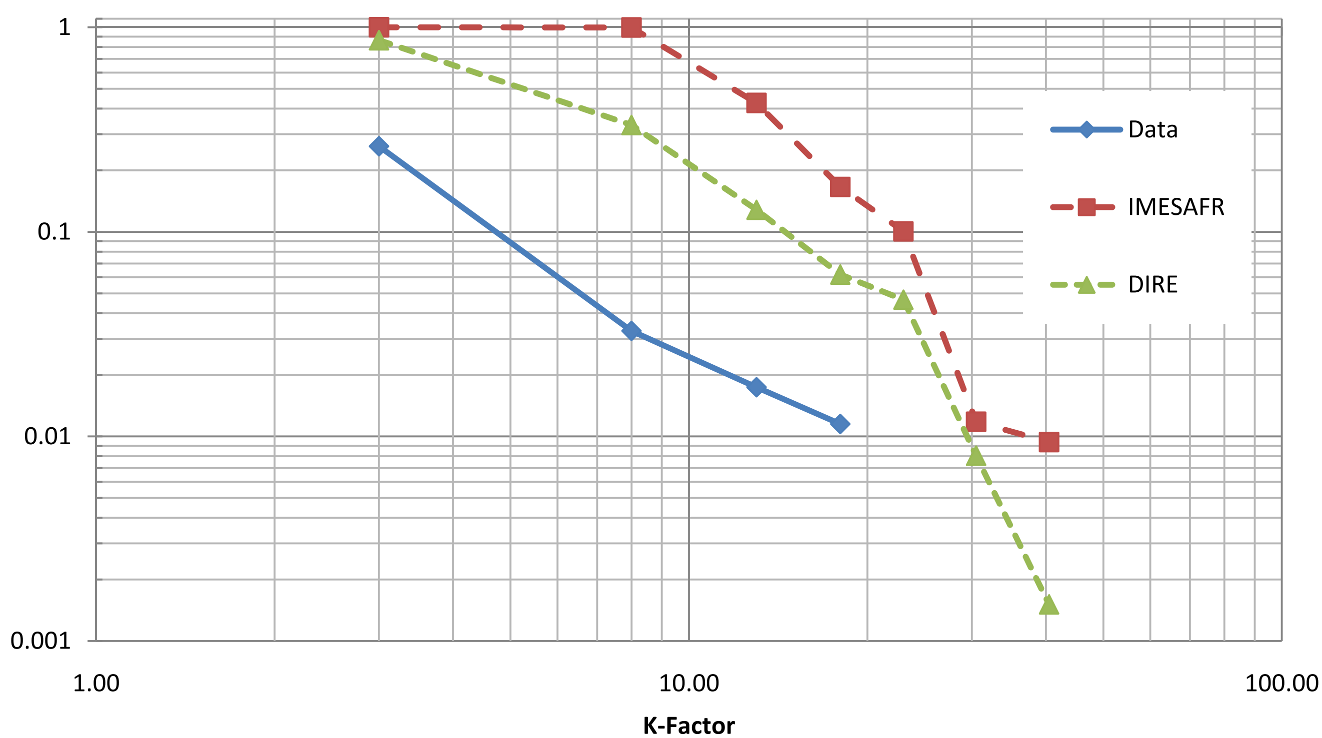

Figure 2. P(f) for exposures not in the open.

[10] "Worst-case" estimate reported in footnote 7.

Several explanations exist for IMESAFR and DIRE over-predicting the consequences, as compared to the Assheton data. This is true for people in structures as well as people in the open. Both programs were designed to "err on the side of caution" to some extent, and both were designed to give best estimates at K40. IMESAFR's and DIRE's predictions at K40 are much closer to the Assheton data than the close-in comparisons. SAFER[11] produces answers very similar to IMESAFR so one would expect similar results with SAFER.

IMESAFR and SAFER employ a logic called the Simplified Close-In Fatality Mechanism (SCIFM) out to a scaled range of around K8 (this values varies by structure type in the models). SCIFM is employed because little data exists in this region and the actual risk in this region is highly dependent on unique local conditions that do not fit into the models. This logic determines a point at which inside that scaled range the structure collapses and all occupants are fatally injured, which is referred to as the *SCIFM Plateau Region*. Beyond the this region out to a scaled range of approximately K12 (again, this values varies by structure type), the *SCIFM Transition Region* connects the close-in plateau to the *Standard Logic Region* that the programs were originally designed to model.

IMESAFR also has an uncertainty routine that affects the point estimate of the answer. As modeled, this uncertainty will always increase the final risk estimate. This may be desirable for general-purpose predictions, but prevents IMESAFR from making a direct comparison to a limited set of actual cases. Uncertainty was not a factor in the Assheton data.

Some differences are attributable to variations in the actual case and the modeled case. This cannot be avoided, whether it is due to lack of information or lack of ability to model some aspects of the actual scenario (like intervening terrain, shielding effects of one building on another, etc). Also, the least pessimistic primary fragment option in both IMESAFR and DIRE are probably conservative representations of the Assheton cases. Other oddities in the model predictions may be due to averaging effects. Finally, it is recognized that grouping scenarios by K-factor can create anomalies when some cases are very small charges with small distances involved and other cases – with the same K-factor – are large charges and large distances. It is important to remember that the cube-root scaling of the charge weight is applicable to the blast effects, but not directly applicable to the debris problem.

The DIRE results are not affected by uncertainty, so they would be expected to be closer to reality. Also, DIRE does not employ a SCIFM routine, although its results are expected to be more conservative as the distance between PES and ES decreases. Since DIRE currently cannot consider barricades, the DIRE predictions would otherwise be lower than shown. Differences in DIRE's predictions for the barricaded and unbarricaded scenarios are due to differences in the scenarios modeled.

Although conservatism affects scenarios with people in the open and people in buildings as modeled by IMESAFR, differences are noticeable. The "Not Open" and barricaded modeled scenarios produced results closer to the Assheton data than open or "Not Barricarded" modeled scenarios. When the risk

[11] Hardwick, Meredith J., Hall, John, Tatom, John W., and Baker, Robert G., "Approved Methods and Algorithms for DoD Risk-Based Explosives Siting,"DDESB Technical Paper 14 Revision 4, 21 July 2009.

from close in cases is dominated by large numbers of small fragments, modeling people in buildings will produce less pessimistic results (unless the building fails). For example, IMESAFR scenarios typically have hundreds of Mass Bin 8 fragments (which have 30 to 100 ft*lbs of kinetic energy). In these scenarios, people in the open will be modeled as being in a very hazardous environment. Each fragment has the potential for causing a fatality. However, people in a wood frame building with plywood sides may receive as much as a 100 ft*lb "credit" in the program. Thus, all the fragments are screened by the walls and the people inside suffer no debris threat.

Relevance of the Data to Modern Scenarios

A valid question remains as to whether 100 year old data is relevant today. Unquestionably, such data will never be generated again because society will not tolerate it. To ascertain the data's relevance to today's scenarios, the major variables that could affect risk were examined individually.

The energy released per unit mass in an event determines factors such as overpressure impulse, debris throw range, and crater ejecta. Dynamite and it components, having been replaced by AN-based explosives, are some of the most powerful and sensitive explosives. They would generate more energy per unit mass and propagate more efficiently than AN-based explosives. Additionally, 98 percent of explosives used today are in insensitive Division 1.5 materials. It is likely that events of equivalent NEW today would be less energetic than 100 years ago.

Although the vulnerability of human beings to injury from trauma has not changed in 100 years, the use of personal protective equipment (PPE) in the workplace has certainly increased. Additionally, today's workplaces have less inherent hazards given an event. Pre-shift safety inspections and tempered glass are just a couple modern practices that remove hazards in the explosives workplace given that an event occurs. Medical treatment has improved greatly in the last 100 years so that a fatal injury 100 years ago may not have been so had it occurred today. On the other hand, it could be argued that workers were less likely to claim injury 100 years ago, that men and women were tougher back then, but there is no indication in the reports that this was the case. To the contrary, many minor injuries such as cuts, bruises, and emotional shock were reported. If any liberalism exists in the data from underreporting injuries, it would probably only affect the ratio of minor to no injuries since death or major injury would have been difficult to cover up. In consideration of all the factors that could affect the degree of injury, the data are probably somewhat conservative.

The type of structure at the PES and ES can have a significant effect on the risk of any given scenario. Table 5 summarizes the effects of relatively strong and weak PES and ES.

Table 5. Effect of Relatively Weak or Strong Structures on Risk

	Strong PES	Weak PES	Strong ES	Weak ES
Increases Risk	More secondary fragments	Less secondary fragments	Larger/heavier pieces fall if building collapses	Less protection from fragments and shock
Decreases Risk	Attenuates shock and primary frags	Little to no effect on shock or primary frags	More protection from fragments and shock	Smaller, lighter pieces of structure fall if building collapses

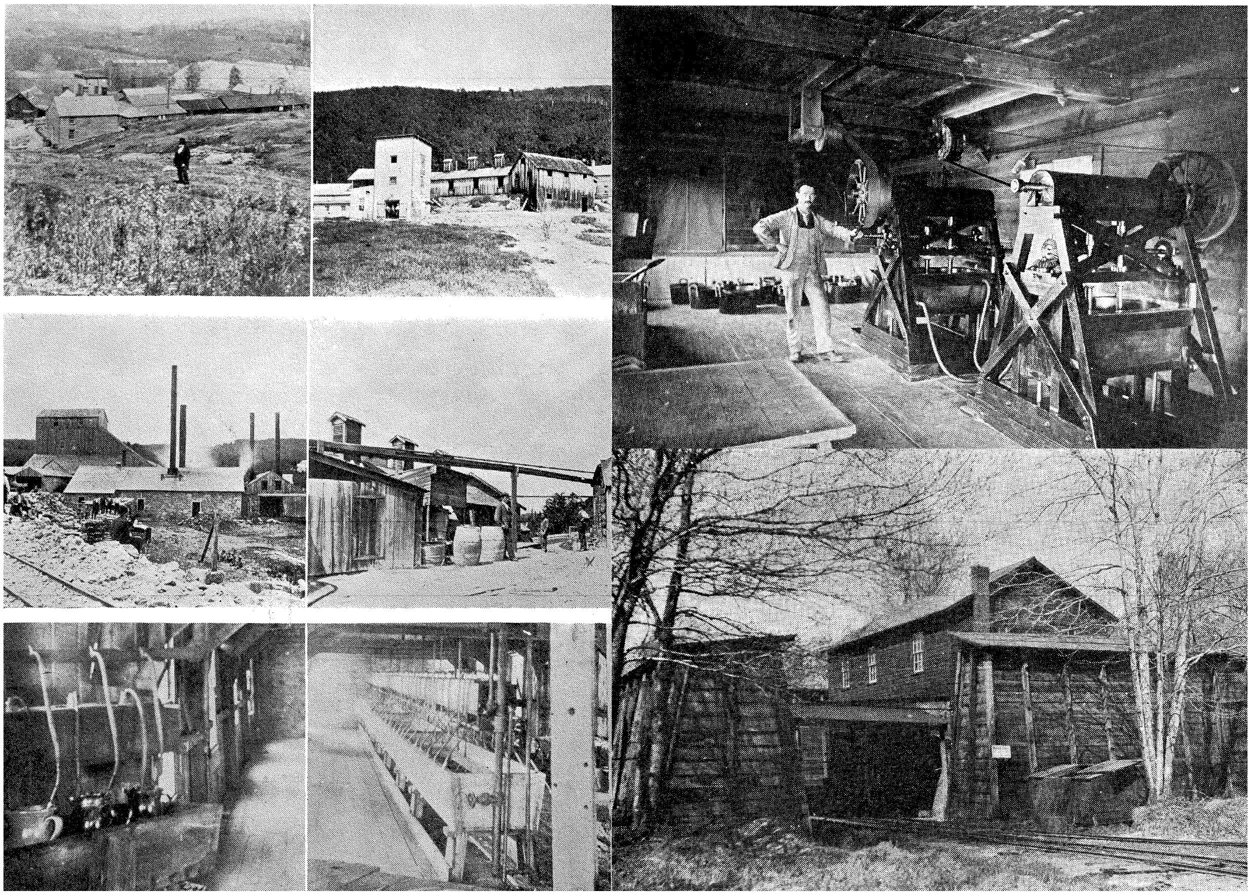

Figure 3. Typical Explosives Plants at the Turn of the 20th Century.

The type of structure at the PES and ES was recorded in the reports, but no detail on construction is provided. About two-thirds of the structures were modeled as wood frame buildings for this study with the rest being unreinforced masonry. So, are PES and ES generally relatively stronger or weaker today as compared to 100 years ago? Does today's manufacturing equipment create more primary fragments than 100 years ago? Figure 3 is a collage of photographs of period explosives plants.[12] Most structures from this period are solid wood frame. A few structures incorporated brick and block and some had tin roofs. Overall, structures were probably weaker than today's operating buildings. The machinery and other equipment used to manufacture explosives today are very different in appearance but would probably create similar primary and secondary fragments. As shown in Table 5, relatively weak PES and ES structures can both increase and decrease risk. In consideration of the type of PES and ES structure, the data do not appear to be overly conservative or overly liberal.

In summary, the numbers of exposures without injury were underreported at higher K-factors, events today of equal NEW would probably be less energetic, the consequences of trauma would probably be less severe today, and the effect of differences in PES and ES is inconclusive. Therefore, the data are probably conservative.

[12] A.P. VanGelder and H. Schlatter, History of the Explosives Industry in America, Columbia University Press, New York, New York, 1927.

Conclusions

The Assheton intra-plant distances report, although nearly 100 years old, provides an irreplaceable and valuable data set for analyzing the consequences of explosive events, especially close to the event. Contrary to popular belief, the primary intent of the IME intra-plant distance table was to prevent exposure of workers to a high probability of death or major injury given an event. Based on the data, the probability of death and injury inside K40 were relatively low. The models conservatively predicted P(f) as compared to the data, but were within about one order of magnitude. Major factors influencing this conservativism are simplified algorithms inside K8, horizontal projectile risk, and uncertainty. Although conditions surrounding explosives manufacturing have changed in 100 years, the changes have not rendered the data irrelevant and overall, the data is probably conservative. The data can serve as an anchor point by which to compare explosive event consequence models.

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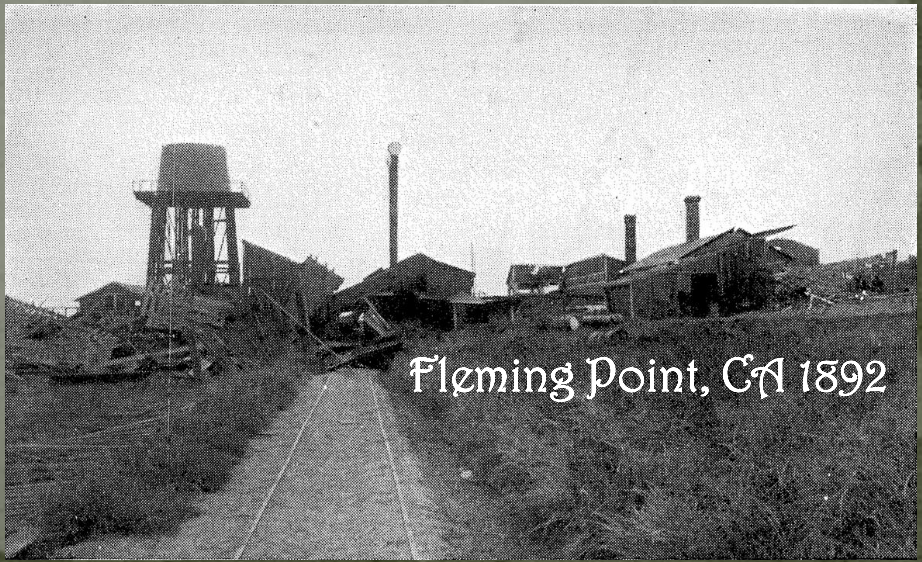
Portland, Oregon · July 13 – 15, 2010



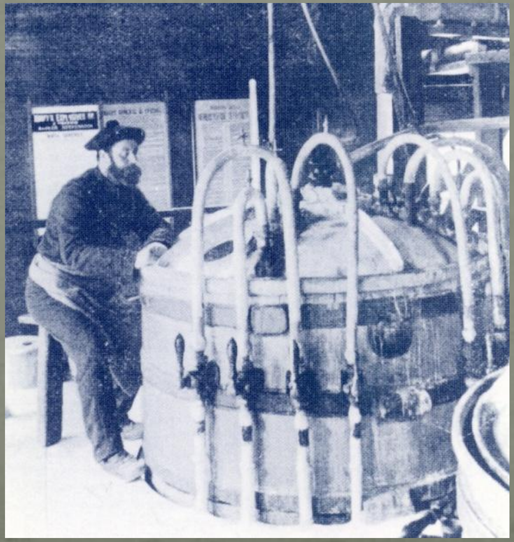
Agenda

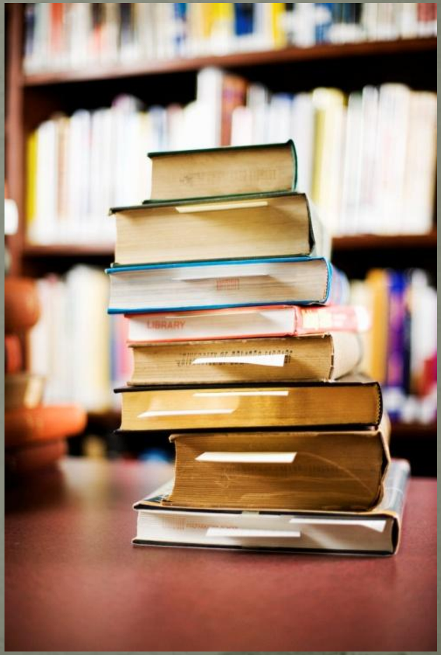
- Describe 100-yr Old Document Found in IME Files
- Discuss the Objectives of the Study
- Look at Data in Document with Modern Methods
- Compare Data to IMESAFR and DIRE Models
- Consider Relevance of Data

Visit by DoD Early 2009

- Researching Origins of DoD Intraline Distance Tables
- DoD Standard Essentially Same as IME Intra-plant Distance Tables
- First Regulation - 1926 New Jersey
- IME SLP-3 1926

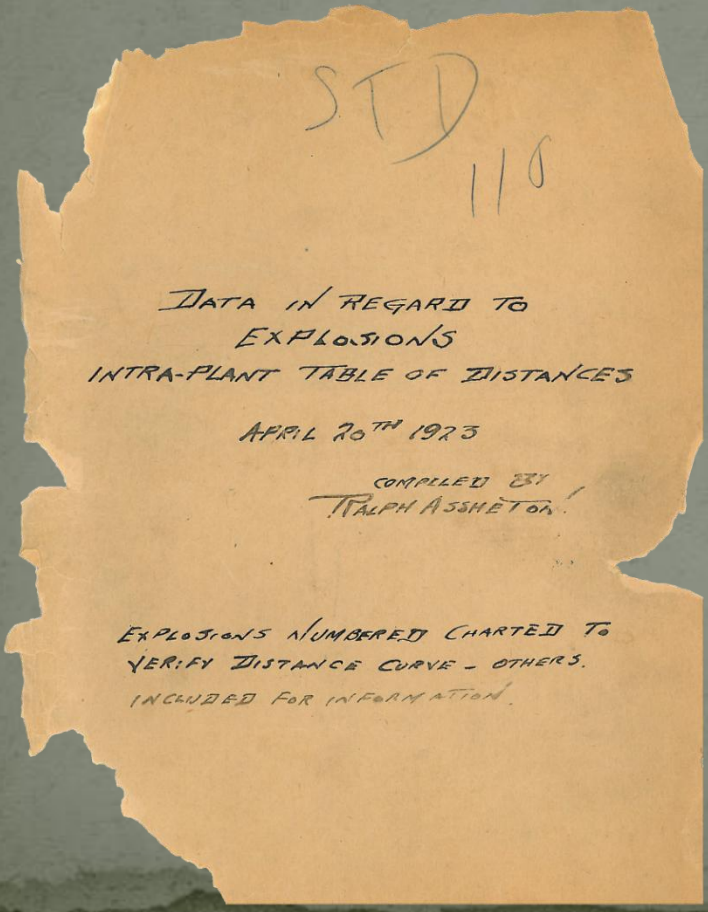

Jersey City, NJ 1891





Document Found in IME Files

- 111 Accidental Explosions
- Survey of IME Members' Incidents from 1880 to 1916



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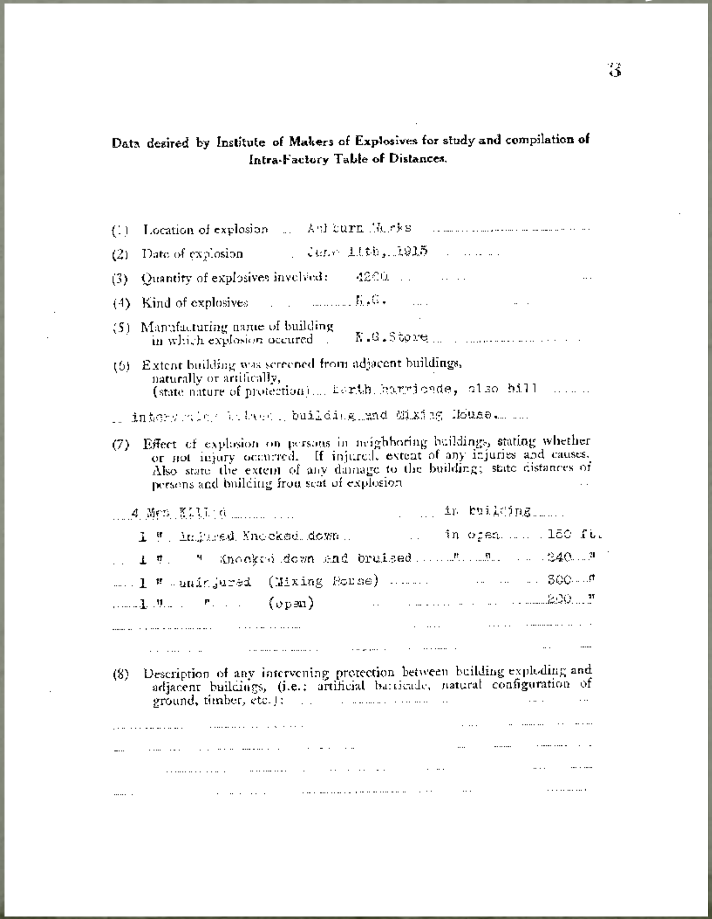
110

DATA IN REGARD TO
EXPLOSIONS
INTRA-PLANT TABLE OF DISTANCES

APRIL 20TH 1923

COMPILED BY
RALPH ASSHETON

EXPLOSIONS NUMBERED CHARTED TO
VERIFY DISTANCE CURVE – OTHERS
INCLUDED FOR INFORMATION



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(1) Location of explosion ... Ashburn Works

(2) Date of explosion ... June 11th, 1915

(3) Quantity of explosives involved: 4200

(4) Kind of explosives ... E.G.

(5) Manufacturing name of building in which explosion occured ... E.G. Store

(6) Extent building was screened from adjacent buildings, naturally or artifically, (state nature of protection) ... Earth barricade, also hill

intervening between building and Mixing House.

(7) Effect of explosion on persons in neighboring buildings, stating whether or not injury occurred. If injured, extent of any injuries and causes. Also state the extent of any damage to the building; state distances of persons and building from seat of explosion

4 Men Killed ... in building

1 " injured Knocked down ... in open ... 150 ft.

1 " " Knocked down and bruised ... " " ... 240 "

1 " uninjured (Mixing House) ... 300 "

1 " " (open) ... 200 "

(8) Description of any intervening protection between building exploding and adjacent buildings, (i.e.: artificial barricade, natural configuration of ground, timber, etc.):

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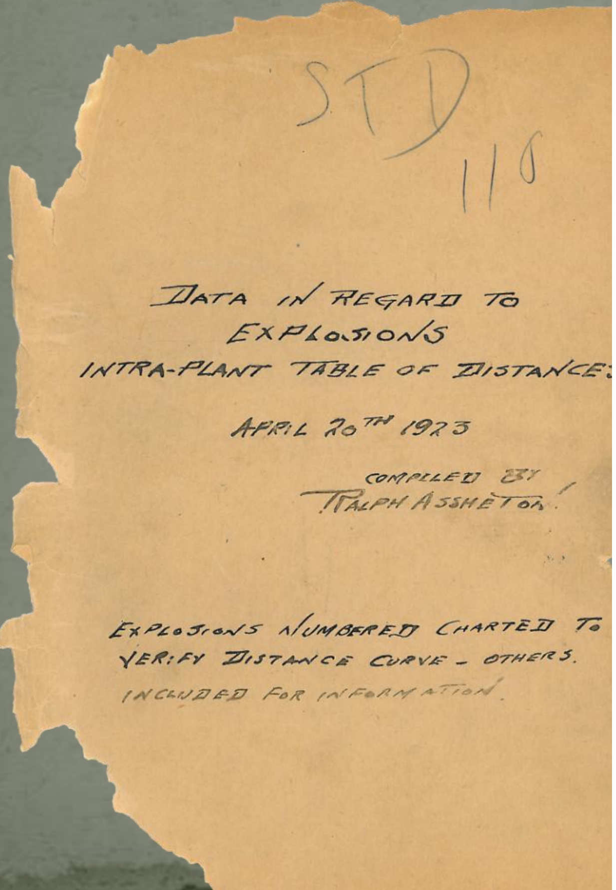
- 111 Accidental Expl
- Survey of IME Mer



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1 " injured Knocked down		in open	150 ft.
1 " " Knocked down and bruised		" "	240 "
1 " uninjured	(Mixing House)		300 "
1 " "	(open)		200 "

(8) Description of any intervening protection between building exploding and adjacent buildings, (i.e.: artificial barricade, natural configuration of ground, timber, etc.): ....

Changing the Paradigm

- Universal Belief that IPQD was Designed to Prevent Propagation
- Minutes of Jan. 26, 1917 IME Meeting
  - IPQD created to protect workers from "serious injuries" and propagation of events.

Fresh Treatment Data

- 92 Events
- 220 Exposure Pairs
- 584 Individuals Exposed to Explosions
- Data Tabulated
  - NEW
  - Distance
  - Type of ES and PES
  - Injuries
    - Fatal
    - Major (off-work, hospital)
    - Minor (first aid)
    - None

The Data in New Light

- Original Study Ignored Number of People in ES
- Probability of Fatality or Injury Desired
- Correlate Injury Type to K-factor of Each Exposure

$$\text{Distance} = K \times NEW^{1/3}$$

$$K = \text{Distance} \div NEW^{1/3}$$

Probability of Injury by K-Factor Bin

- Created Bins for Ranges of K-factors
- Calculated Probability of Injury for All Exposures within Bins

K-factor Bin
1-5
6-10
11-15
16-20
21-25
26-35
36-45
46+

Oppau, Germany 1921

K-factor Bin	Fatalities		Major Injuries		Minor Injuries		No Injury		Total
1-5	17	33%	9	17%	7	13%	19	37%	52
6-10	3	4%	11	15%	15	20%	46	61%	75
11-15	2	2%	4	3%	52	43%	62	52%	120
16-20	1	1%	2	2%	19	20%	73	77%	95
21-25	0		1	1%	14	20%	55	79%	70
26-35	0		2	3%	19	25%	55	72%	76
36-45	0		1	1%	3	7%	42	91%	46
~~46+~~	~~0~~		~~0~~		~~20~~	~~40%~~	~~30~~	~~60%~~	~~50~~
Total	23		30		149		382		584

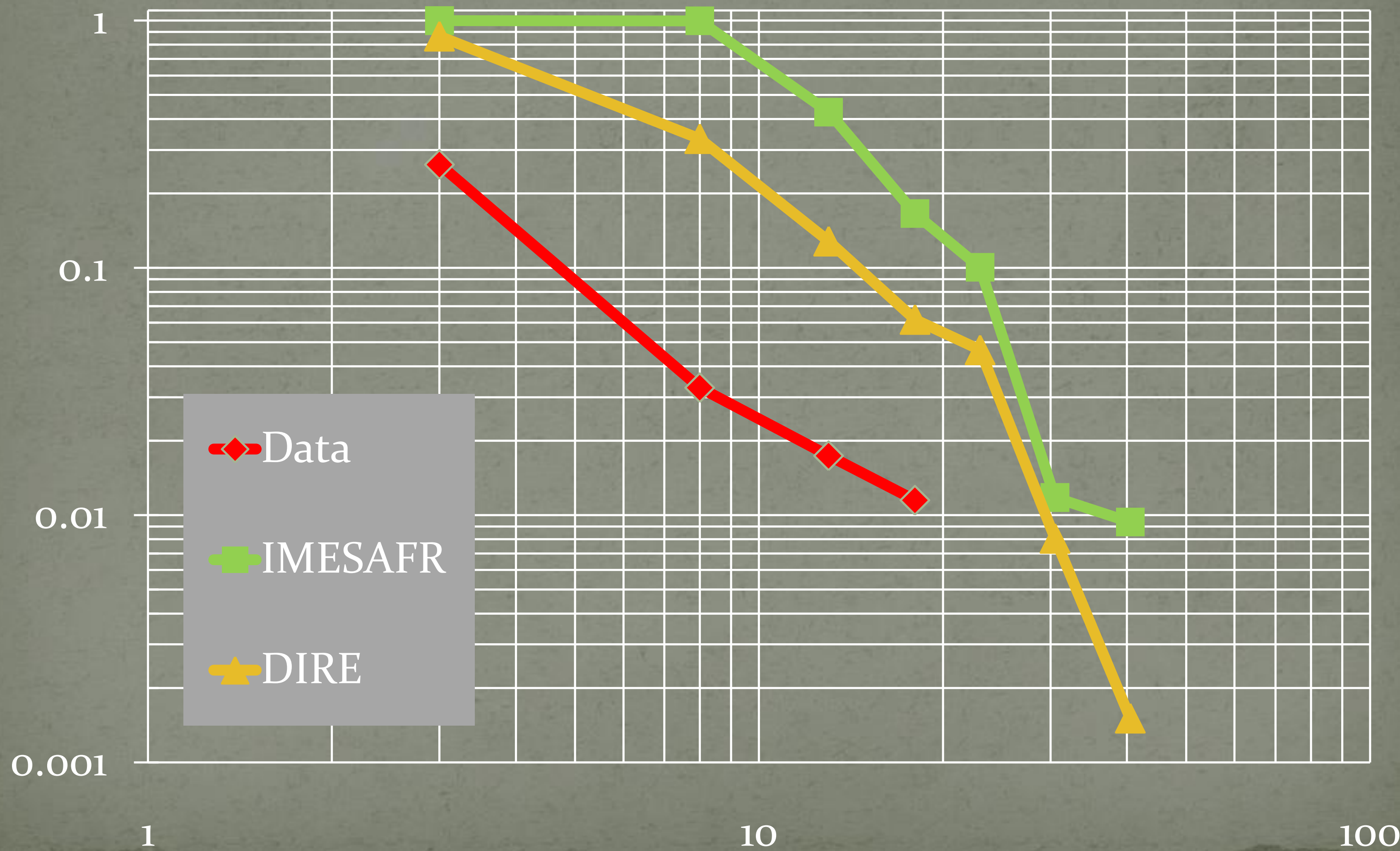
Black Powder, Being in the Open, and Barricades

- Each had 10-15% of Exposures
- BP Events Included in Analysis
  - No Difference in Data Sets
    - Same average K-factor for minor injuries
    - Student's t-test: no difference exists
- People in the Open
  - Much less risk in the open beyond K10
- Barricaded People
  - Much less risk inside K20

P(f) of Data and Models

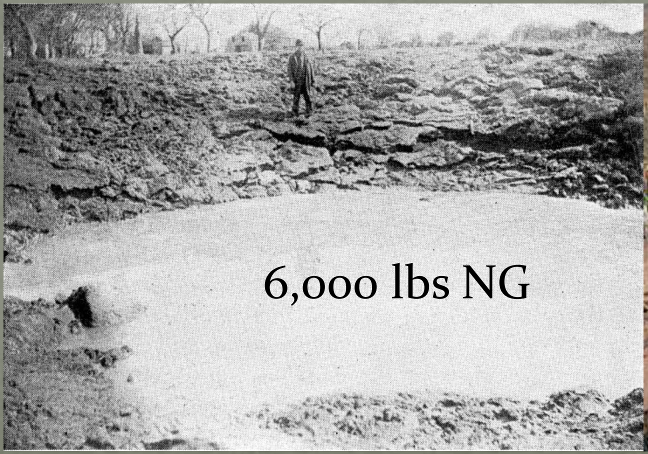
K-factor Bin	Not Open			Open			No Barricade			Barricade		
	Data	IMESAFR	DIRE	Data	IMESAFR	DIRE	Data	IMESAFR	DIRE	Data	IMESAFR	DIRE
1-5	0.26	1	0.86	0.60	1	1.0	0.35	1	0.90	0/4	1	0.67
6-10	0.033	1.00	0.33	0.071	0.92	0.21	0.045	1.0	0.29	0/9	1	0.41
11-15	0.017	0.43	0.13	0/5	0.30	0.11	0.019	0.50	0.13	0/17	0.23	0.14
16-20	0.011	0.17	0.062	0/8	0.10	0.028	0.012	0.21	0.061	0/11	0.065	0.073
21-25	0/52	0.10	0.047	0/18	0.0094	0.012	0/63	0.10	0.061	0/7	0.083	0.0088
26-35	0/67	0.012	0.0081	0/9	0.0031	0.0075	0/57	0.017	0.0092	0/19	0.0045	0.0046
36-45	0/41	0.0094	0.0015	0/5	0.0026	0.010	0/39	0.013	0.0029	0/7	0.0015	0.00034

P(f) for 465 "Not Open Exposures"



Is the Data Relevant Today?

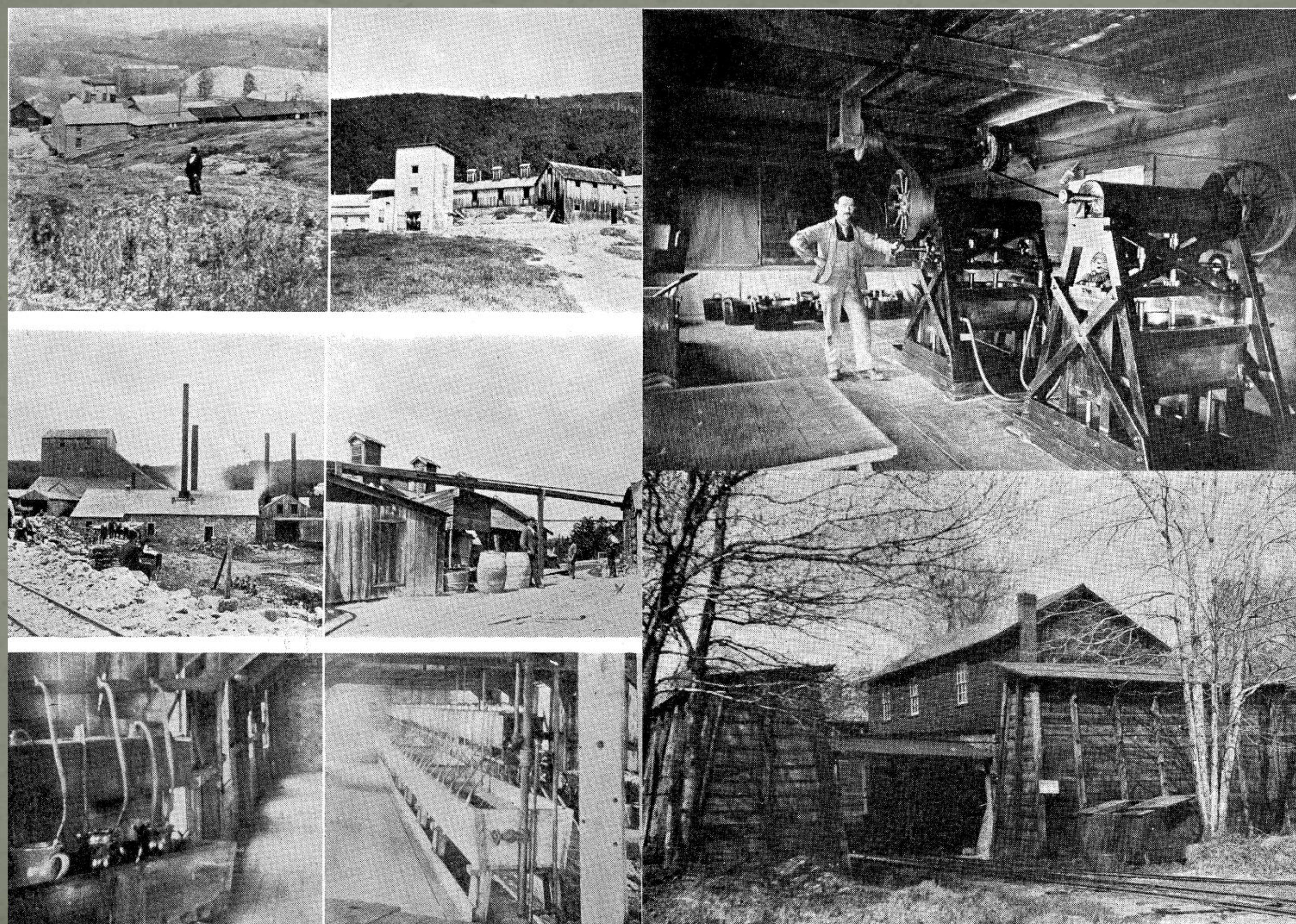
- It Will Never be Recreated
- So it is Extremely Valuable if Relevant
- Major Factors to Consider
  - Explosive energy per unit mass
  - Human vulnerability
  - Building Construction
    - PES
    - ES



Relevant Factors

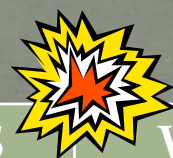
Factor	Data	Today	Relevance
Energy	Dynamite, Black Powder	AN-Based, Division 1.5 and 5.1	Data is Conservative
Vulnerability	Possible Underreporting Minor Injuries	Better PPE/Safer Work Area, Better Medical	Data is Conservative
Construction	Wood Frame	Concrete, PEMB	Next Slide

Typical 1900 Construction



Effect of "Strong" and "Weak" Structures

- Data Not Overly Conservative or Liberal



	Strong PES	Weak PES	Strong ES	Weak ES
Increases Risk	More secondary fragments	Little to no effect on shock or primary fragments	Larger, heavier pieces fall if building collapses	Less protection from fragments and shock
Decreases Risk	Attenuates shock and primary fragments	Less secondary fragments	More protection from fragments and shock	Smaller, lighter pieces of structure fall if building collapses

Conclusions

- IPQD Protects Workers Given an Event
- Models are Conservative but Close; P(f) x ~10
  - SCIFM < K8
  - Horizontal projections
  - Uncertainty
- Data is Probably Conservative